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First Mirror Design Options for the ITER core CXRS diagnostic

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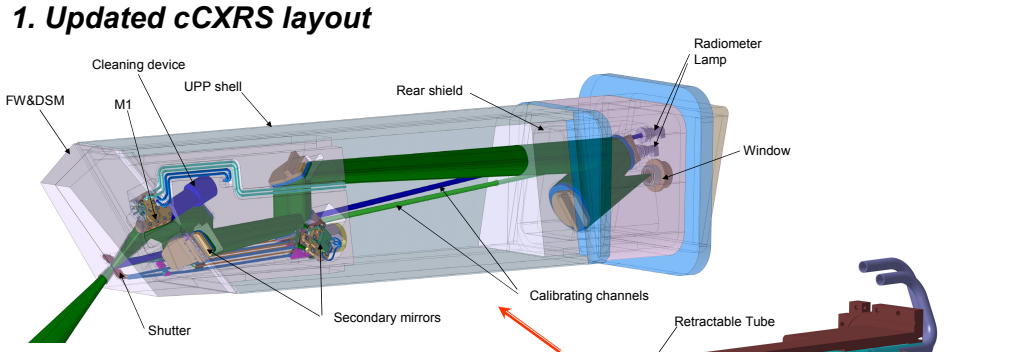
Background:

- ***The ITER core charge exchange recombination spectroscopy (cCXRS) comprises the upper port plug #3 (UPP 3) with a set of optical mirrors. Its main function is to transfer the light emitted by interaction of the plasma ions with diagnostic neutral beam (DNB) to the diagnostic spectrometers.***
- ***The first mirror (M1) development is based on the updated cCXRS layout of 2011.***
- ***M1 is cooled during plasma pulse and kept at elevated temperature ("thermal conditioning") of ~300ºC by gas (He).***
- ***The M1 lifetime is a critical issue. It is expected to be determined by plasma impurities deposited as mixture of C, Be with He isotopes, W and SS compositions. Typical particle fluxes on the FW: 10^{21} ^{1}/m^{2}s (D, T), 10^{19} ^{1}/m^{2}s (Be, C), <10^{17} ^{1}/m^{2}s (W). The M1 is to be cleanable and cleaned.***
- ***Loads: neutron heating ~ 0.2 W/cm^3, radiation flux – up to ~ 4 kW/m^2, mirror EM twisting/tilting moments[4] - ~1.48/0.79 kNm.***
- ***M1 can be aligned around x axis within ±2 Deg.***

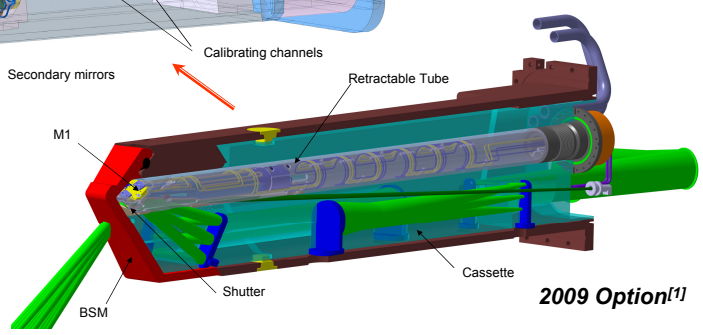
Objectives:

- ***Developing the generic design solutions for M1 unit of the updated core CXRS including the first mirror, M1 cooling loops, M1 holder and its support structure.***
- ***Integration of the first mirror into the DSM/cCXRS and ITER generic UPP layouts.***

1. Updated cCXRS layout



2011 Baseline

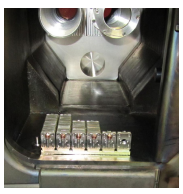


2009 Option[1]

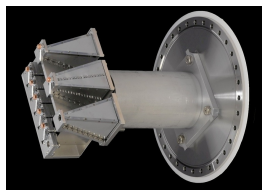
cCXRS 2011 Baseline (from the left) and reference of 2009 (from the right) options

Main improvements of the updated cCXRS layout are:

- ***Prolonged M1 lifetime (due to small entrance pupil, longest distance from the FW to M1, baffles system to be installed between the FW and M1 [2,3] (baffle's efficiency will be verified by tests).***
- ***Planned "in-situ" cleaning system (to be developed).***

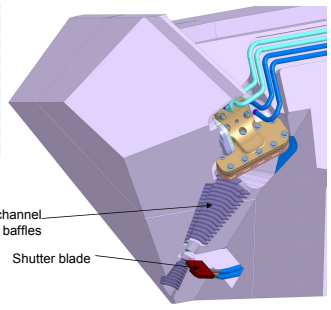


DIIID Mirror Station



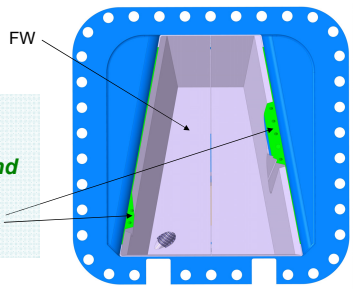
TEXTOR Mirror Station

Mirror stations <–> baffles' efficiency verification



Main disadvantages are:

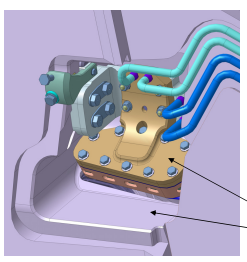
- ***Large cut-outs to be implemented into the DSM for the mirrors and shutter location do the DSM structure complex.***
- ***Primary neutrons can reach the shell butt and heat the shell, M1 and M2 locally (to be protected by plugs in addition).***

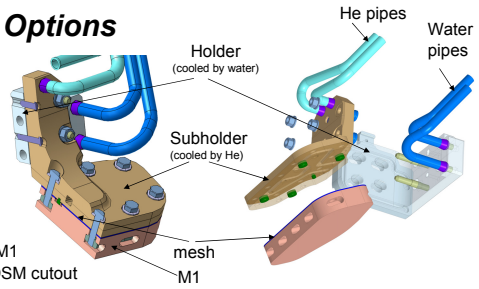


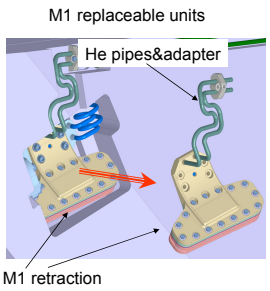
2. General M1 design requirements

*-**M1 lifetime**: 20 years with cleaning.*
*-**Material**: keep a performance under erosion and deposition conditions; should tolerate mirror surface recovery/cleaning.*
*-**M1 positioning tolerances**: displacements – within ±0.2 mm, angular deviations - < ±3.5 mrad*
*-**Mirror stability during thermal transients and steady-state:** within ±2 mm and ±1.75 mrad.*
*-**Admissible thermal-mechanical distortions**: curvature and irregularity - within ± 27 μm.*
*-**M1 positioning stability after re-assembly**: ± 0.1 mrad and ± 0.1 mm.*
*-**Admissible heating of the coolant (He)** : up to 40K.*
*-**UPP neutron shielding**: the number and dimensions of the DSM cutouts are to be minimized.*
*-**Compatibility with ITER generic UPP concept**: be compatible with minimum possible customization.*
*-**Mirror assembly/re-assembly/maintenance by RH tools**: be compatible.*

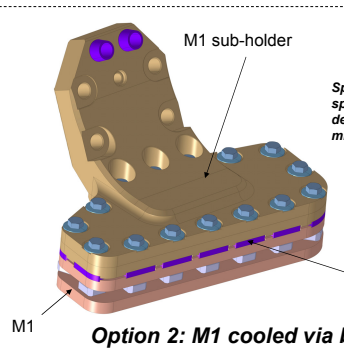
3. Main M1 Design Options



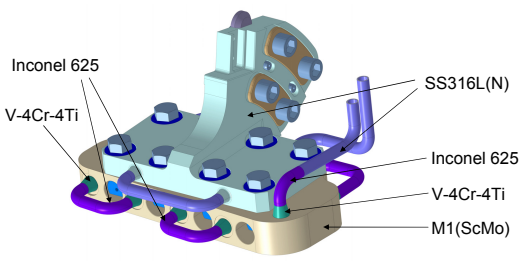


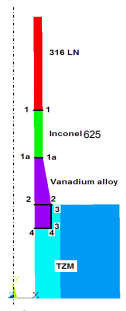


Option 1: M1 cooled via compressed (papyex nuclear grade) mesh (t=2 mm)



Option 2: M1 cooled via brazed mesh



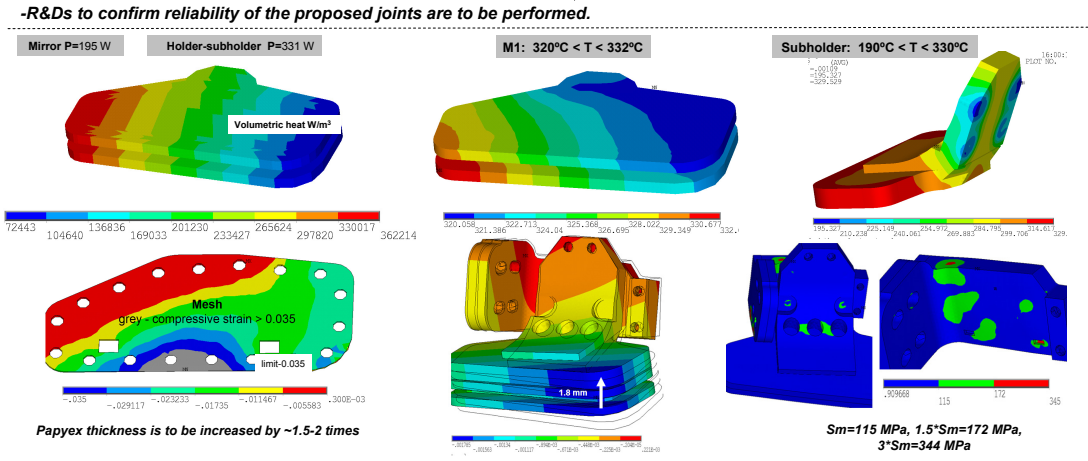


Option 3: M1 heated & cooled directly by He

-Welding technologies are to be tested&verified.
-R&Ds to confirm reliability of the proposed joints are to be performed.

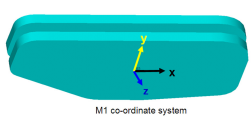
Assumed M1 temperature is 350ºC

Stress category	Material	Section	Tresca, MPa	Allowable stress, MPa
Membrane and bending	SS	1-1	252	3Sm=327
	Inconel 625	1-1	257	3Sm≥729
	Inconel 625	1a-1a	286	3Sm≥729
	V-alloy	1a-1a	272	3Sm=354
	V-alloy	2-2	150	3Sm=354
	Mo	3-3	519	3Sm=669
	V-alloy	3-3	301	3Sm=354
	Mo	4-4	372	3Sm=669
	V-alloy	4-4	341	3Sm=354



Papyex thickness is to be increased by ~1.5-2 times

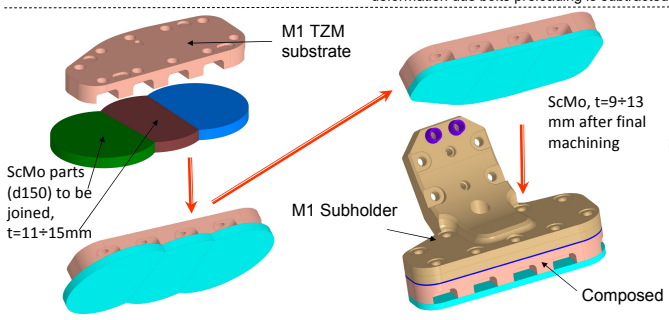
Sm=115 MPa, 1.5*Sm=172 MPa, 3*Sm=344 MPa

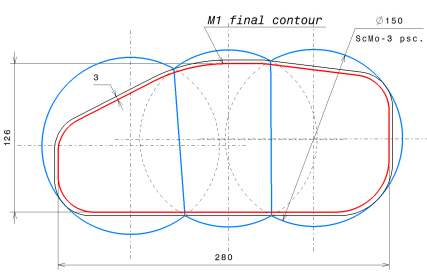


Distortion of M1 surface

Distortion	Ztran, mm	Rot_Y, mrad	Rot_X, mrad	Curvatures, fringes/μm	Irregularity, fringes/μm
Admissible range	±2	±1.75	±1.75	±100/±31.6	±100/±31.6
1. bolt preloading	0.048	0.011	-0.107	1.98/0.624	14.7/4.65
2. He, Water – In*	-0.319	-0.635	-0.408	20.5/6.48	11.9/3.75
3. Neutron heat*	-0.337	-0.739	-0.287	41.5/13.1	14.5/4.57

*deformation due bolts preloading is subtracted





Optional solution: M1 composed of several ScMo pieces

Diffusion weld&HIP&brazing by STEMET are planned for the testing

Conclusions

- ***The new cCXRS baseline layout is compatible with ITER generic approaches. Considerable customization of the diagnostic shielding and first wall modules is required. The DSM with cutouts can be equipped with some plugs. The port plug design can be further optimized by reducing dimensions of the DSM pockets and cutouts, and eliminating/minimizing the pockets' overlapping volumes.***
- ***The M1 lifetime can be a showstopper for the cCXRS availability. The in-situ cleaning device, shutter and DSM baffled optical duct improves the mirror optical performance. The baffles' efficiency is under verification in the TEXTOR, DIIID and ASDEX UPGRADE experiments with the use of mirror's stations.***
- ***The developed design options for the large M1, proved by analysis, are mainly workable, flexible, scalable and robust. Size of the ScMo pieces available on the market dictates the necessity of the mirror consisting of several ScMo parts jointed to Mo-alloy substrate.***
- ***R&Ds are required for the mirrors' structures: the directly cooled M1, brazed/compressed mesh, ScMo parts joining, ScMo-TZM connection.***

References:

[1] S.Sadakov et al., Conceptual design of the ITER upper port plug for charge exchange diagnostic, Fus.Eng.Des.,84,2009,1671-1675.
[2] F.Klinkhamer et al,. Optimization of the availability of the core CXRS diagnostics for ITER, Fus.Eng.Des.,86,2011,1174-1177.
[3] V.Kotov et al., Numerical estimates of the ITER first mirrors degradation due to atomic fluxes, Fus.Eng.Des.,86,2011,1583-1586.
[4] A.Panin, et al., Approaches to multifield numerical analysis for components of ITER cCXRS upper port plug diagnostics, SOFT 27(2012), P3-102.

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